

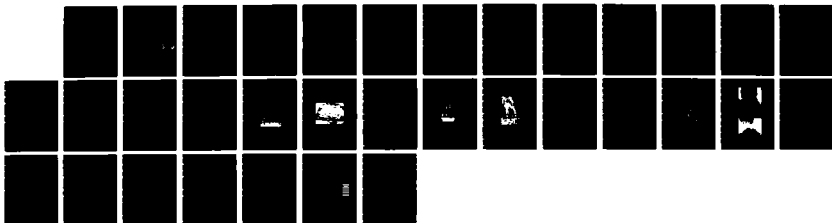
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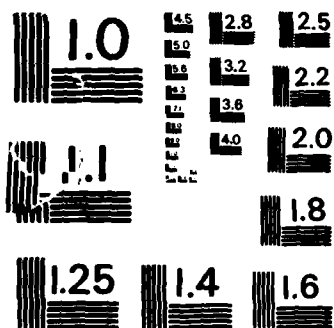
ANTIFRATRICIDE PROTECTION FOR PALLETIZED CHEMICAL  
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TECHNICAL REPORT BRL-TR-2711

ANTIFRATRICIDE PROTECTION FOR  
PALLETIZED CHEMICAL ROCKETS  
DURING SHIPMENT

Ona R. Lyman  
John T. McLaughlin

February 1986

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## I. BACKGROUND

The US Army has a large number of M55 chemical rockets in storage which it needs to destroy. These rockets are located at various places in the US. Three options are available for their disposition: (1) they may be left where they are stored, (2) they may be incinerated at facilities to be built at the storage sites, or (3) they may be shipped to a few incineration sites for destruction. The last two options involve moving the rockets either within an installation or across the country. Several studies have been made to determine the consequences of these possible scenarios, with emphasis on finding the safest method.

The maximum credible event (MCE) for moving pallets of these rockets is the spontaneous detonation of one rocket on a pallet, with a sympathetic detonation of another rocket warhead, and massive leakage of agent from the remaining 13 rockets, (Dept of Defense Explosive Safety Board estimate). Tests to measure the magnitude of such an event have been made at Tooele Army Depot, Utah.<sup>1</sup> The Ballistic Research Laboratory (BRL) was asked to consider the use of antifratricide techniques to reduce the magnitude of such an accidental detonation. In a very quick look at the problem, the BRL<sup>2</sup> concluded that such techniques, along with total containment of the accident in a pressure vessel, could be a viable approach. Considerable testing would be required to determine accurately how best to accomplish this goal, and the reliability of the design to perform its intended function.

## II. OBJECTIVES

Antifratricide devices have a wide variation in design and construction depending on what is to be accomplished. Much of the previous work of the BRL Explosives Effects Branch has been directed at vehicle ready stores where the principal goal is the saving of the vehicle and crew, given a detonation of one round, by preventing other rounds from participating in the event. The situation for this study is similar, but more restrictive, in that in addition to preventing propagation of reaction it is also desirable to keep damage to adjacent rounds to a minimum. Obviously, one can reduce the effects on adjacent rounds to zero given enough space and intervening material. Our task, however, is to accomplish this within practical space and weight constraints. Furthermore, two scenarios are considered, one where rockets remain palletized and one where rockets are removed and placed in a different configuration possibly suitable for confinement in a containment vessel of some kind.

The most desirable solution would be to insert suitable antifratricide material between the rockets, both nearest neighbors and next nearest neighbors, without disturbing the rockets or their palletized configuration. If this turns out to be impractical, either because of insufficient space, or because propagation of reaction cannot be prevented, then depalletization will have to be considered.

## III. APPROACH

Although the BRL has extensive experience in the design and test of antifratricide devices for use with HE filled munitions, it has no experience with configurations like the M55 rocket where the explosive fill is surrounded



by a layer of liquid, see Figure 1. In principle this would appear to be a much less severe situation than the standard explosive filled projectiles that are normally dealt with in antifratricide work, because the liquid provides some protection from both shock initiation and fragment impact. However, the thin wall of the warhead provides very little protection to the explosive charge. Even more significant is the low flash point of the ethylene glycol agent simulant in the M61 rockets used for these tests, 121°C (250°F). When a donor warhead is detonated a fireball results which has a much longer duration than that associated with the detonation of the explosive charge alone. This does not create much of a problem if pallets of rockets are tested in the open as was the case for the Tooele tests. In the test setup used here, however, we must contain fragments and rocket components for safety reasons, and now we have the post detonation debris confined within a steel cylinder along with the fireball. As a result flammable materials (wood pallet material, fiber glass shipper/launcher tubes, and any flammable antifratricide materials) are ignited and long duration fires result. These fires have the potential of igniting rocket motors and initiating burning or more violent reactions in explosive filled burster tubes.

Initial tests used a donor and two acceptor rockets with separation distances the same as those in a row of palletized rockets, and the saddle portions of a pallet both beneath and above the rockets are included in all four positions. The array was bound together with steel strap 3/4 inch wide as is used on the pallets. The donor rocket has its fuse removed and a tetryl booster is placed directly against the lead charge and initiated with an RP80 exploding bridge wire detonator. Antifratricide material is placed between donor and acceptors and the test is initiated. In a similar manner, tests using tubes to hold the rockets were tested for depalletized configurations. Once the antifratricide requirements have been established for these configurations further tests using either nine or seven rockets in either a rectangular array or a hexagonal array will be tested to include the effect of confinement experienced in a full pallet.

#### IV. TEST RESULTS

All tests described in this section were performed inside an open ended, thick walled, steel tube 3.6 meters long and 1.1 meters in diameter. This fact makes these tests much more severe than the tests at Tooele<sup>1</sup> which were performed in the open. For safety reasons this was the only allowable method for the BRL ranges.

The first three tests were designed to provide a quick look at the antifratricide problem to see how severe it was. The first test used wood dunnage with one donor rocket and two acceptor rockets flanking the donor. Antifratricide bars of 19 mm by 50 mm polyethylene were placed between the warhead sections of the rockets. When the donor was fired there was an intense fire which lasted for about 15 seconds, followed by a much less intense fire from burning dunnage and rocket shipping launcher tubes. Post shot examination showed that the explosive had been burned out of the acceptor warheads and that all the rocket motors had also burned. For the next shot the wood dunnage was eliminated and the rockets were placed in aluminum tubes with a 133 mm inside diameter, and a 3 mm wall thickness. These tubes were separated the same distance as the rockets are when they are palletized. Elimination of the wood

dunnage reduced the duration of the long term fire although the initial fireball was no different from the previous test. Again both acceptor warheads were ruptured and the explosive had burned through the fuse end after the fuses had been knocked off by the original blast. The donor motor had also burned. The third test used 19 mm by 38 mm rectangular cross-section tubing to simulate a pallet configuration, and had 50 mm by 50 mm polyethylene bars between donor and acceptors. The results of this configuration were not substantially different from the two previous tests. Both the acceptor rocket warheads had the explosive burned out through the fuse end of the warhead and the donor rocket motor burned. These results indicate that protecting the acceptor warheads is more difficult than had been anticipated. Further, it is apparent that ignition of the donor motor is a severe problem which must be addressed. Figures 2 and 3 are pre- and post-test photos of test number one.

Aluminum tubing with a wall thickness of 9.5 mm and an inside diameter of 127 mm was selected as probably being adequate to protect the warheads given a spacing comparable to that used in the pallet configuration. Aluminum plates 610 mm long by 203 mm wide and 12.7 mm thick were cut with a centered hole 146 mm in diameter to support the donor tube and similar holes centered 197 mm on either side of the centered hole to support the acceptor tubes. Three such plates were used to support the three tubes. The forward plate was 228 mm aft of the front of the tubes, the mid plate was placed 902 mm aft of the forward end of the tube, and the third plate was placed 305 mm forward of the aft end of the tubes. The aluminum support plates were also drilled to allow 38 mm diameter polyethylene rods to be placed between the warheads in the plane of the donor and acceptor burster tubes. Figure 4 is a sketch of this configuration. Figure 5 is a post-test photo of this shot, note burned out burster tubes.

When the donor was detonated, we experienced the usual 15 second burn of the ethylene glycol, followed by small fires which lasted about 2 minutes. Following this there were a few very small flames probably from the polyethylene rods. At thirty minutes after the initial detonation of the donor, there was a second mild explosion. Post-test evaluation indicated that it was probably a fuse. The aluminum tubes around the acceptor warheads survived although they were badly dented, both acceptor fuses were knocked off, and the explosive in the burster tubes was burned out. All three motor sections were recovered, but the motor propellant grain on the donor rocket was exposed. It was recessed about 300 mm in the aluminum tube which may explain why it did not ignite.

The next test was similar, but, 12.7 mm diameter pins were inserted across the diameter of the aluminum tubes at the fuse end, to try to keep the fuse in place and thus protect the burster explosive from exposure to the burning ethylene glycol vapor. This test, number five in this series, was fired with the modifications described above. Additionally, the polyethylene antifratricide bars were replaced with 41 mm thin wall electrical conduit in an attempt to reduce the amount of flammable material present. The donor warhead was detonated and was followed immediately by the burning of one rocket motor. Major burning subsided after about two minutes. Small fires continued to burn fueled by the liquid ethylene glycol and the fiber glass shipper/launcher tube fragments. Thirty minutes after the original detonation of the donor warhead there was a second explosion after which no more flames were observed. Post-shot examination of the debris allows the following sequence of events to be

postulated. Detonation of the donor warhead caused the donor motor to ignite and burn, and also broke the left acceptor tube and rocket at the point where the motor and warhead join. The acceptor rocket motor was expelled from the aluminum tube and its burster tube was also ignited at about this time. The motor section apparently was not directly exposed to the flames so it did not ignite. The motor casing was exposed to the long duration small fires, and did cook off after about thirty minutes. The reaction was violent. It split open the motor case and flattened it. The right hand acceptor did not experience this trauma and both warhead and motor were recovered.

This test was repeated (shot #6) with only minor adjustments to the positioning of the mid support plate. It is believed that the position of the mid support plate is critical as it is necessary to try to keep the base plate of the warhead section and the forward closure plate of the motor section in place to protect the motor from the fireball. This test was a total success with all motors and both acceptor warheads recovered intact. As encouraging as this is it must be repeatable, so further tests are required. Figure 6 is a photo of this test prior to firing. Note the pins in the tube ends to constrain end caps.

Test #6 was repeated twice more in an attempt to duplicate the results. In both cases the donor motor burned although both acceptor warheads and motors survived. In short, it appears that a portion of the problem has been solved, but unless the donor motor can be made to survive, any attempt to confine the system in a vessel is out of the question. Because survival of the donor motor is the crucial issue, it was decided to use only one rocket in subsequent tests and try various techniques to insure motor survival when the warhead was detonated.

The rationale for the next series of tests is to try to prevent the base of the warhead and the forward steel closure plate on the warhead section from ejecting and exposing the motor to the fire from the warhead detonation. Figure 7 is a cross-section of this portion of the M61 rocket. It is believed that this can be accomplished by careful placement of the mid support plate and by reinforcing the aluminum tube with a steel collar to keep it from expanding. The first attempt was made with the mid support plate placed 838 mm from the forward end of the aluminum tube with a steel collar 152 mm long and 19 mm thick around the aluminum tube immediately aft of the mid support plate. Figure 8 is a sketch of this configuration. The test was fired and the rocket motor was ejected and burned. The aluminum tube sheared at the steel collar and the collar and tube were both belled some. The collar appeared to be too far forward. The collar and mid support plate should be moved aft about 75 mm for the next shot.

The next three shots in this series were made with the steel collar and plate moved aft 75 mm. These shots resulted in one success, one partial success, and one failure. The partial success was a case where the motor did not burn, although it was exposed and probably would have burned, except the ethylene glycol did not ignite on this shot. The motor was exposed and actually protruded about 254 mm from the motor case. It is apparent that this technique is not reliable enough to ensure that the donor motor will not ignite when the donor warhead is detonated.

In over 80% of the tests thus far, the donor motor has been ignited and with one exception ignition has always come from the burning of the ethylene glycol fill in the warhead. There is no reason to believe that M55 rockets will behave any differently as the agent flash point is not that different from that of ethylene glycol. Unconfined tests may reduce the probability of ignition some, but the potential is always there. The problem is not insurmountable, but probably does require some dismantling of the individual rockets and would be a labor intensive operation. The next two tests, described below, are a quick fix designed to demonstrate a possible approach.

The problem of protecting the rocket motor still faces us, and it is apparent that there are no easy solutions. Based on a suggestion by Mr. Nicholas Hagis, US Army Materiel Systems Analysis Activity, a last attempt to prevent the motor from igniting when the warhead is detonated was made. One rocket was removed from its shipper/launcher tube and the fins were removed. This exposed the nozzles on the motor. The rocket was then placed upright with its nose down and a very wet mixture of sand mortar was made and poured into the interior of the motor. Figure 7 shows the cavity at the forward end of the motor which must be filled. After the mortar had been allowed to set, the rocket was reinserted into its shipper/launcher tube and used as a donor in the next test. In addition to the modified donor rocket, two acceptor rockets (unmodified) were placed one on either side of the donor, but with a separation between the aluminum tubes of 127 mm and with a section of thinwall electrical conduit 41 mm in diameter between the warhead sections. Figure 9 is a sketch of this configuration and Figure 10 is a pre-shot photo. The object of this additional spacing was to determine how much the damage to the warheads could be reduced. This test was a complete success. The motor was not ignited and post-shot examination showed that there was a layer of mortar still intact in the free space at the forward end of the motor, which was unaffected by the burning of the ethylene glycol. Also the damage to the acceptor warheads was extremely light. Both acceptor aluminum tubes were dented about 12 mm but neither of the rockets were leaking any ethylene glycol. Figure 11 is a post-test photo. Note the reduced damage to the aluminum tube around the warhead section. This test was repeated with identical results.

#### V. SUMMARY OF TEST RESULTS

The task undertaken turned out to be much more difficult than had been anticipated. Combustible dunnage is a very severe problem because the secondary fires after the detonation of a rocket ignite any exposed propellant or explosive. Consequently, although antifraticide material placed between rockets can keep the adjacent rockets from reacting at the time of the initial explosion the follow-on fires that occur usually cause reactions which, because the antifraticide material is no longer in place are more violent than the initial detonation. Attempts to use the available intrapallet spacing were not truly successful as it was not possible to prevent massive leaking and exposure of the explosive and the motor propellant.

The use of 9.5 mm wall thickness aluminum tubes to surround and support the rockets proved to be very effective in preventing excessive damage to the warhead sections of the acceptor rockets, even at separation distances only

slightly greater than the intrapallet spacing when used with suitable antifratricide material between the tubes. The most suitable material tried was thin wall electrical conduit 41 mm in diameter. Polyethylene rods 50 mm in diameter worked well also but contribute to the post-detonation fires.

The most serious problem encountered in these tests was prevention of ignition of the donor rocket motor. Without modification of the rocket, it was impossible to reliably prevent ignition of the donor rocket motor with any of the techniques used. The ignition source for the motor was the burning ethylene glycol simulant used in the warhead. In an open unconfined environment, this might not be a problem, but one would then experience the dissemination of the simulant even if it did not burn. The approach used was to try to keep the motor propellant from being exposed to the fire after donor initiation. The variety of techniques tried were notably unsuccessful, with the exception of tests where the fins were removed and the cavity at the front of the motor was filled with mortar. Although this technique is cumbersome and may not be practical for a large scale operation, it does solve the problem of donor motor ignition.

Concurrent with the tests using mortar in the donor motor, the separation between donor and acceptor rockets was increased to 127 mm which was double that used on earlier tests. Doubling the separation should reduce the forces exerted on acceptor rockets by a factor of four, except of course for fragment hits. The post-examination of acceptor rockets showed a marked reduction in damage. Warheads were dented slightly with the maximum depression of the sidewall being 12 mm. None of the acceptor rocket warheads were leaking in either of these tests. A larger sample size would probably produce some leakers but the massive leaking experienced on earlier tests would surely be avoided.

Another essential item for successful tests is the placement of a pin through the aluminum tubes at both ends to keep the end caps on the shipper/launcher tubes from being knocked off by the donor blast. For the tests using close spacing it was essential that these pins be in place, otherwise the fuses were frequently knocked off exposing the burster explosive which was generally ignited. With pins in place, ignition of the acceptor burster explosive was never experienced.

## VI. CONCLUSIONS

The starting point for this program was to assume that one rocket warhead, in a palletized configuration, detonates. The goal then is to reduce the magnitude of deleterious effects resulting from this event. In addition, it is also desirable to keep the rockets on their pallet and minimize the handling of the rockets. The positioning of antifratricide materials between rockets while they are on the pallet is not an easy task. The end cover must be removed from the forward end, and the side two by fours which are between the saddles must also be removed, then whatever materials are required can be put in place and the two by fours and end cover replaced and the pallet restrapped together. This is a time consuming and labor intensive task, and unless the antifratricide material really does a good job probably not worth the effort. Dunnage fires will still occur, and fuses will still be knocked off with the potential for burning of the burster explosive.

The test program performed indicates that much more protection can be provided by depalletizing the rockets and placing them in aluminum tubes with a wall thickness of about 9 mm. If one could then reliably prevent the motor on the rocket that detonates from igniting, then one could arrange for total confinement of the entire load of rockets. It is not easy to accomplish this, and probably requires the injection of some flame-proof material into the cavity at the forward end of the motor section. For this reason, total confinement of a package of rockets is considered a less viable option, although still a feasible task. Because of the work required to make the motor section of a rocket less susceptible to ignition, it may be more practical to remove the fuse and explosive charge, depending on the hazard involved in that operation.

The best protection for the warheads was provided by inserting the rockets into aluminum tubes with a wall thickness of 9 mm, and separating the tubes 127 mm. Placing a section of thinwall electrical conduit between the tubes in line with the warhead section, and inserting pins through the tube ends to keep the end caps in place completed this test configuration. Tests on this configuration demonstrate that warheads adjacent to the donor warhead survive, and in the limited number of tests performed, no leakers were generated. An insufficient number of tests were fired to obtain statistics on the probability of generating leakers and undoubtedly some will be generated given enough shots. These tests also had the motor on the donor round modified to prevent ignition when the warhead was deliberately initiated.

In summary the following statements are made.

- I. Application of antifratricide techniques to palletized rockets is not a viable option because:
  - a. The pallet dunnage will burn causing additional problems.
  - b. Separation distances are too small to provide adequate protection even with the best techniques known.
  - c. Without some method to keep the end caps of the shipping tubes in place, the fuses will be knocked off in any detonation and the burster explosive will be ignited.
- II. The most effective protection discovered in this test series is to insert the rockets into aluminum tubes of suitable diameter with a 9 mm wall thickness and separated by 127 mm, sections of 41 mm diameter thinwall electrical conduit are then placed midway between the rockets in line with the burster tubes. This technique, along with the placement of a pin in each end of the aluminum tube to keep the end caps in place, resulted in minimal damage to the warheads adjacent to the donor warhead. This system is sketched in Figure 9. Figure 10 is a photo of this configuration. Figure 11 shows the effect of donor detonation; note the damage to the warhead sections and compare it to that from smaller spacing shown in Figure 6.
- III. The results described in II above were obtained with the forward end of the motor section of the donor motor filled with a mortar mix that was allowed to harden before the test was initiated. This

may not be a practical approach for the real world even if some other material is used other than mortar, as it was necessary to remove the rocket from its launch tube and remove the fins before it could be modified. However, if necessary, this approach would allow the total containment of the rockets in a containment vessel for shipment.

- IV. Because it is necessary to remove the rockets from their pallet and use a new package similar to that described in II above, if safety in shipment is a primary goal, it might well be worth considering the removal of the fuse (remotely) and removal of the burster explosive for separate disposal. One pallet load of rockets which were to be used as donors had their fuses removed and the explosive was readily accessible. In any event such options should be considered in view of the ] or required to prepare rockets for safe shipment.

An M55 assessment study is currently in progress under the auspices of the US Army Toxic and Hazardous Material Agency which is examining all components of the M55 rocket. Its purpose is to determine the condition of all components and determine the extent of any deterioration that may have occurred, and the possible effects on demilitarization procedures. Pending the results of this investigation, and in light of the problems experienced in these tests relative to preventing the ignition of donor motors, it is suggested that consideration should be given to some disassembly of the M55 rocket prior to shipment. Possible approaches might be either removal of the warhead from the motor section or removal of the fuse from the warhead and then removal of the explosive from the burster tube, or perhaps both. Fuses were removed by Combat Systems Test Agency (CSTA) personnel from one pallet of the M61 rockets used in this test series to provide donor rounds. The work was done remotely and the rockets were not removed from the pallet, and for this small sample none of these rockets leaked.

TABLE I. List of Tests

<u>Test #</u>	<u>Test Conditions</u>	<u>Results</u>
1.	Wood dunnage, pallet spacing, poly AF bars	Long term fire all HE and motors consumed
2.	1/8 inch wall thickness Al tubes in contact no AF bars	All HE consumed, donor motor burned acceptor motors survived
3.	3/4" X 1-1/2" Al tube dunnage 2" X 2" poly AF bars	All HE consumed donor motor burned acceptor motor survived
4.	5" I.D. Al tubes 3/8" wall 3 1/2" Al support plates 1-1/2" poly AF bars	All motors survived donor motor exposed all HE consumed
5.	Same as 4. but poly AF bars replaced with 1-1/2" thinwall electrical conduit pins at tube ends to hold fuses in	Donor and one acceptor motor burned one acceptor warhead survived
6.	Same as 5. but mid support plate moved aft to 35" from forward end of tube	All motors survived both acceptor warheads survived
7.	Same as 6.	Donor motor burned one acceptor warhead burned
8.	Only donor rocket tested steel collar around tube just aft of warhead	Motor expelled from tube and burned
9.	Same as 8 but collar moved aft to 36" from forward end of Al tube	Motor survived, warhead base and motor closure plate in place protect motor
10.	Same as 9	Motor survived but exposed
11.	Same as 9	Motor burned
12.	Same as 9 but energy absorbing block at aft end of rocket	Motor burned



TABLE I. List of Tests (continued)

<u>Test #</u>	<u>Test Conditions</u>	<u>Results</u>
13.	Donor rocket only with Al tube and collar around motor only	Motor burned although it was not exposed at either end
14.	Same as 13	Motor was expelled but did not burn, no ethylene glycol fire occurred
15.	Rocket modified by filling cavity at forward end of the motor mortar; space between donor and acceptor rockets double that of earlier tests	Donor motor survived as well as both acceptor motors, acceptor warheads survived with no leaking of simulant
16.	Same as 15	Same as 15

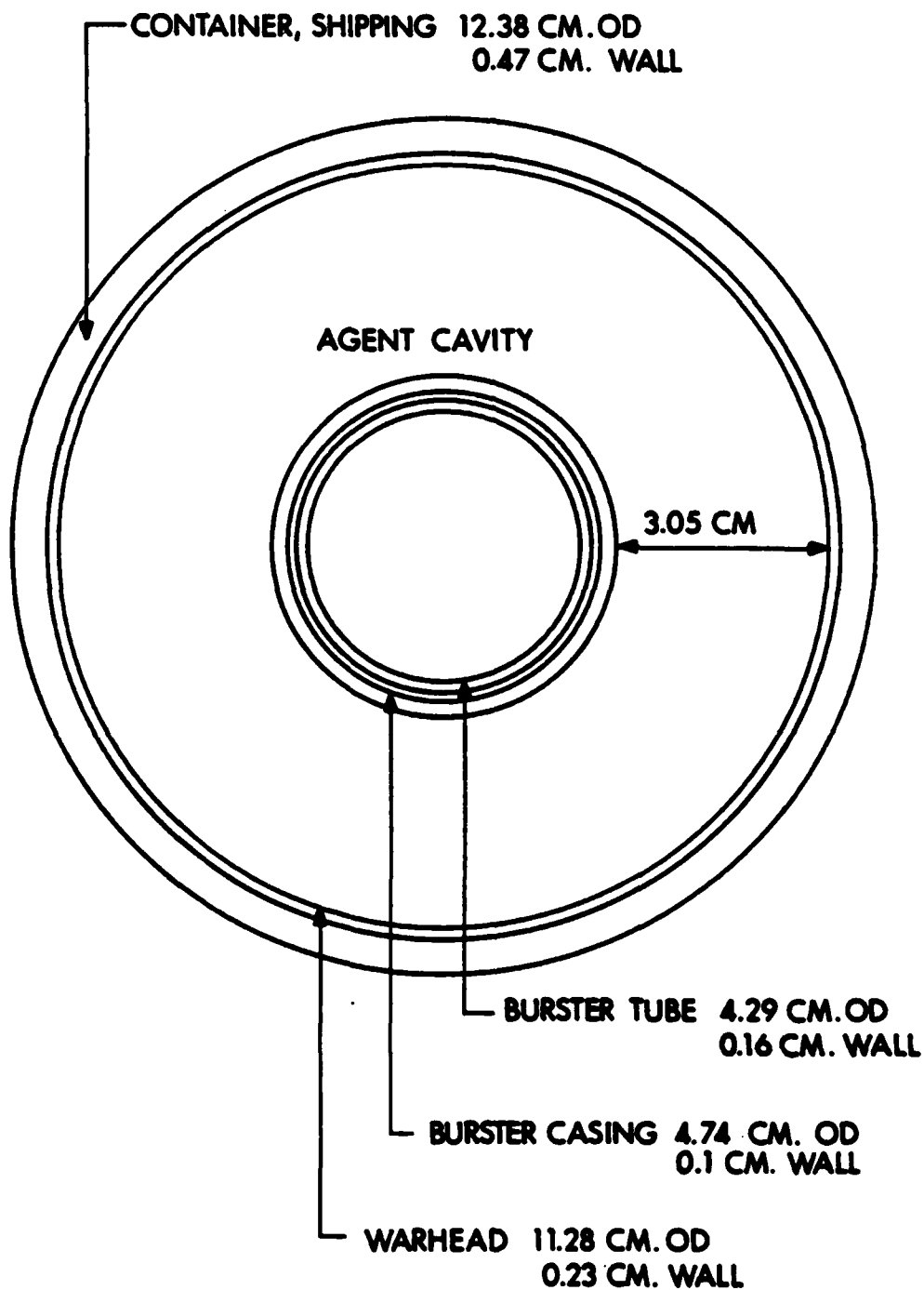


Figure 1. Cross Section of M61 Rocket Warhead at the Midpoint.

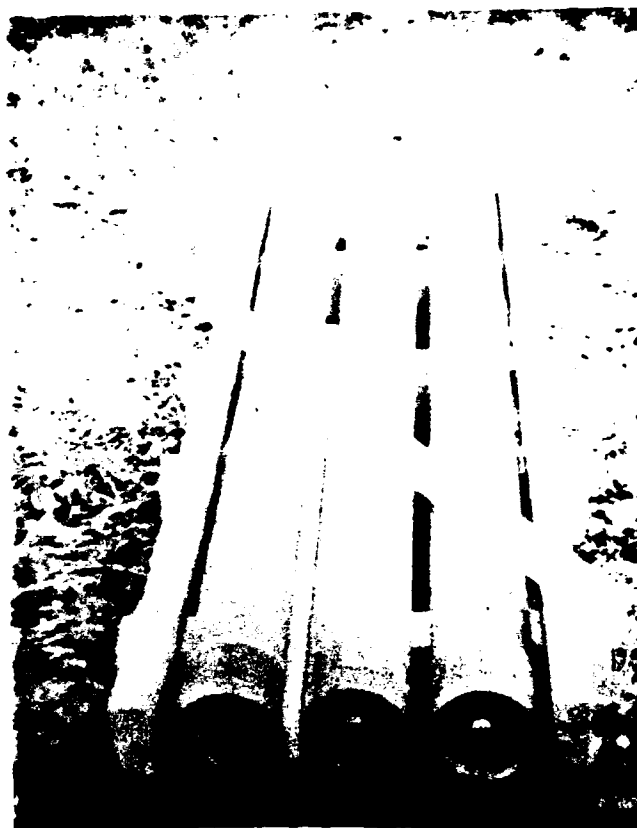


Figure 2. Photo of Test Simulating Palletized Configuration. Photo Taken Prior to Installation of Top Saddles and Bands.



Figure 3. Photo of Debris Remaining After Firing Test in Figure 1.

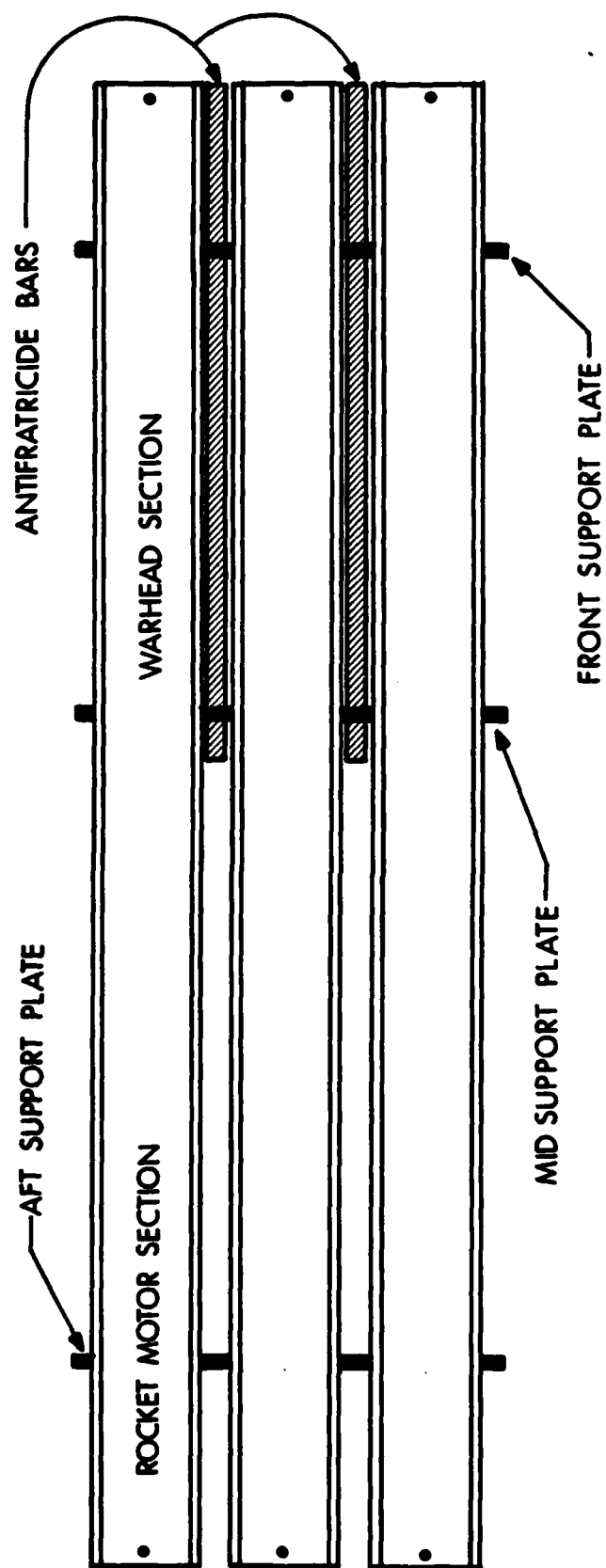


Figure 4. Drawing of Configuration Using Aluminum Tubes and Support Plates with Provision for Antifraticide Devices Between Warheads.

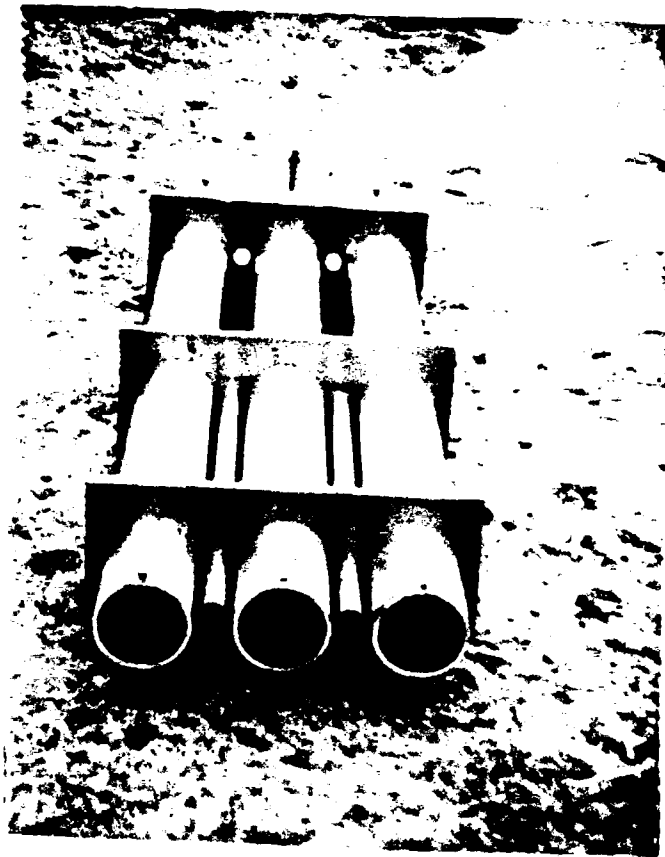


Figure 5. Photo of Aluminum Tube Configuration, Note Pins at the Ends to Keep End Caps and Fuses in Place.

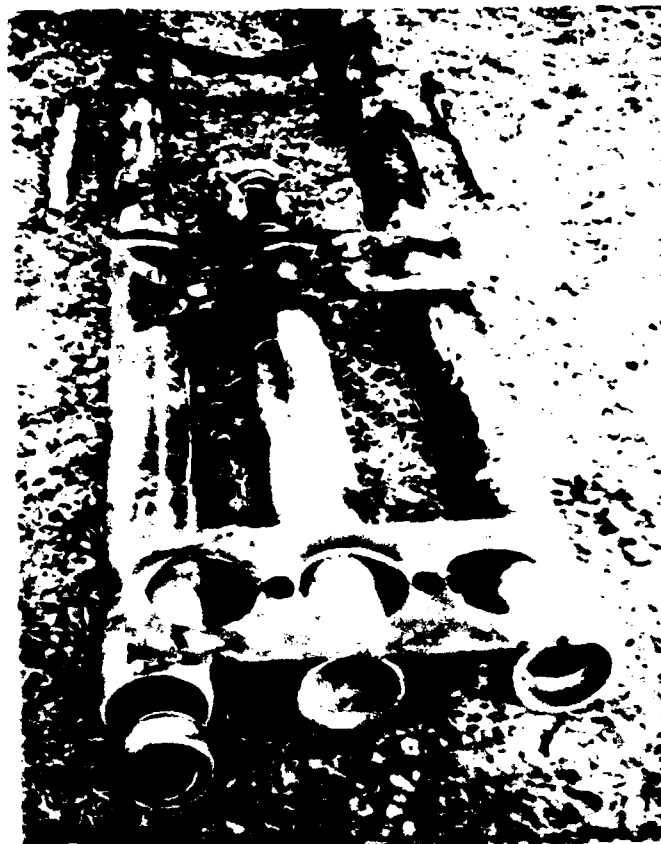


Figure 6. Post Test Debris from Aluminum Tube Configuration, Note Extent of Damage to Acceptor Warhead Section and Compare to Later Test with Increased Donor Acceptor Separation.

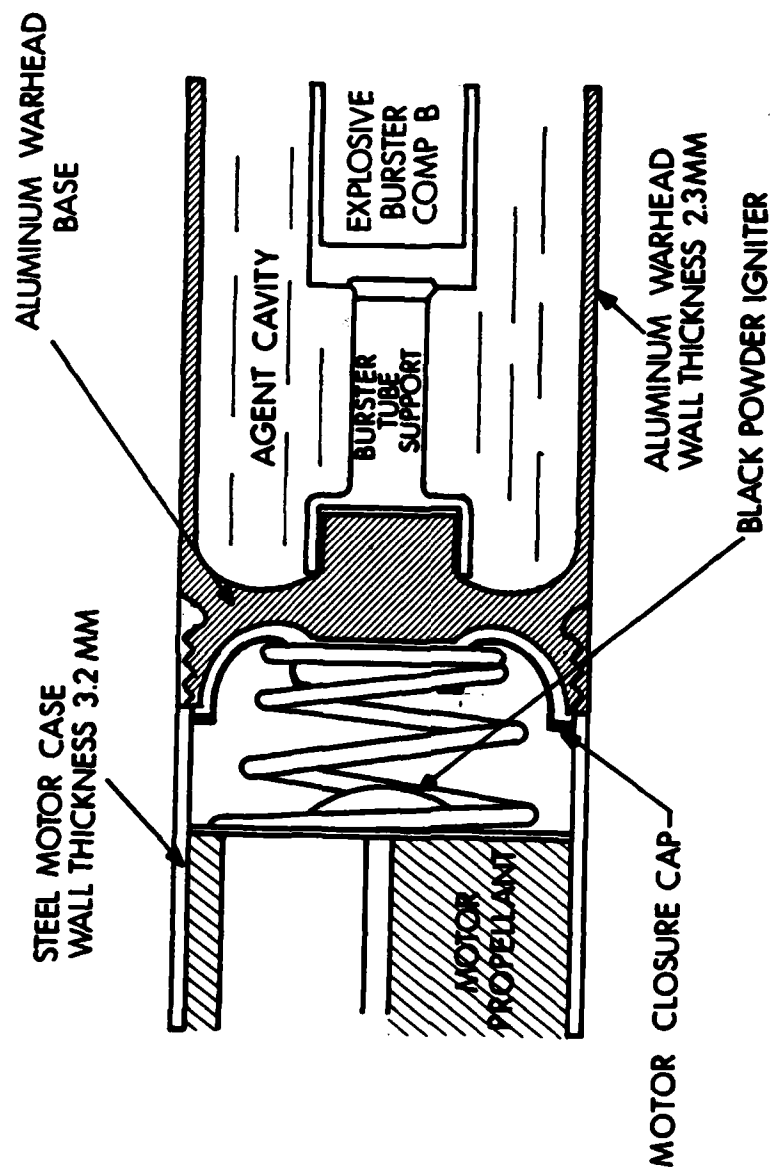


Figure 7. Axial Cross Section of M61 Rocket at the Juncture of the Warhead and Motor Sections.



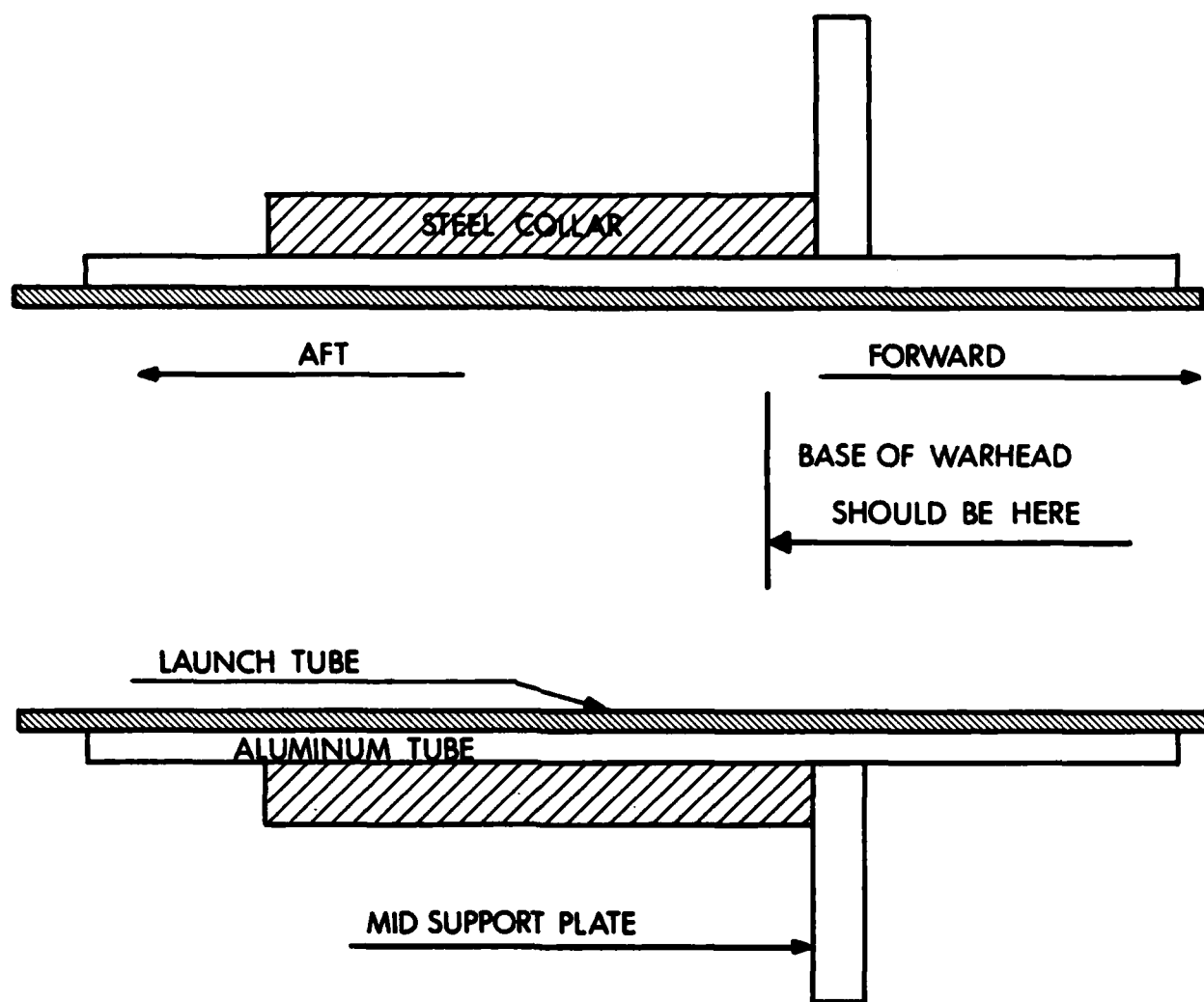


Figure 8. Sketch of Reinforced Section of Donor Tube Used to Keep Forward End of Motor Closed.

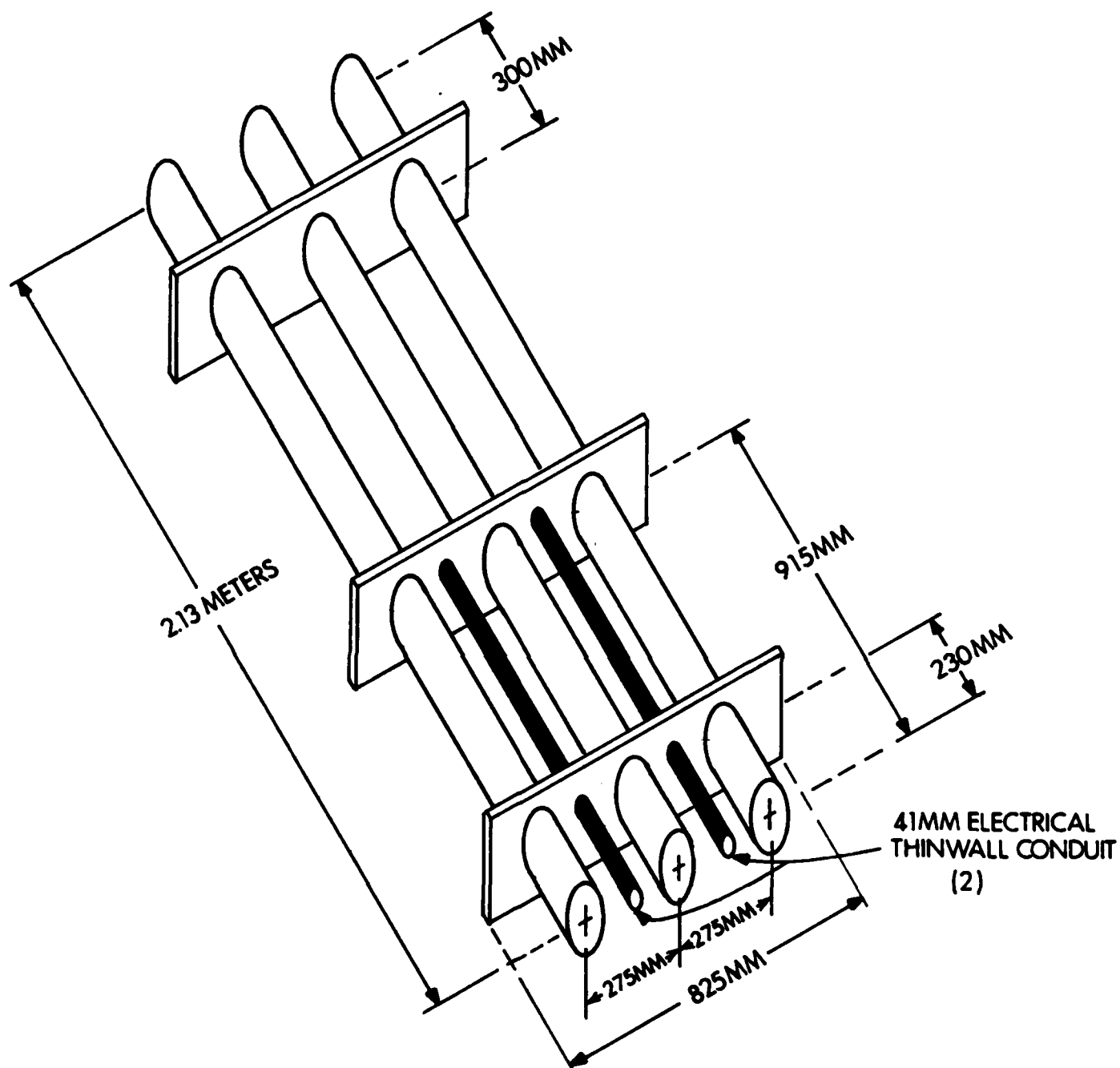


Figure 9. Sketch of Wide Spaced Tube System where Modified Donor Motors Were Used.

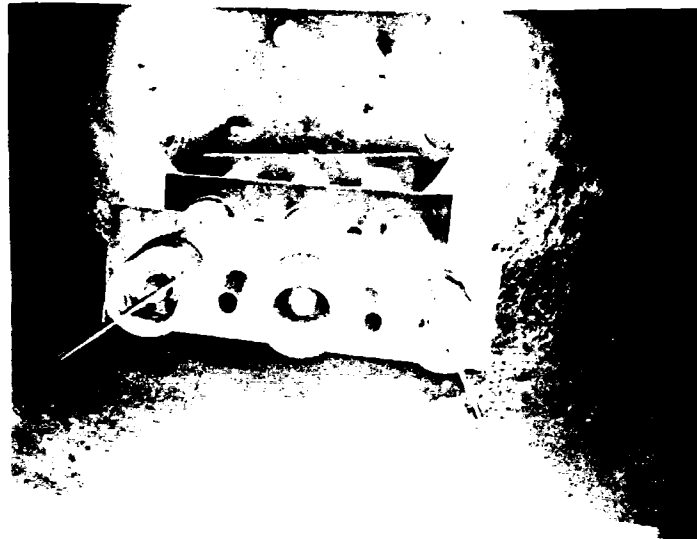


Figure 10. Photo of Wide Spaced Tube Configuration Before Firing.

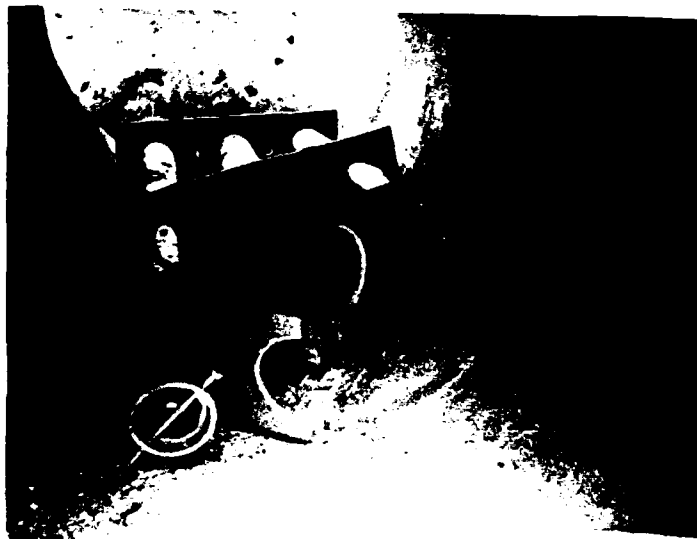


Figure 11. Photo of Wide Spaced Tube Configuration After Firing.

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2. Lyman, O.R. "Application of Suppressive Shielding and Antifratricide Technologies to the Transport of M55 Rockets," BRL Memorandum Report BRL-MR-3420, Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland 21005, Dec 84.

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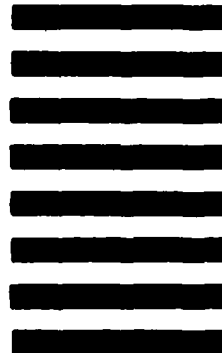


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